NPS55-80-009

NAVAL POSTGRADUATE SCHOOL

Monterey, California

AN ALGORITHM FOR POSITION DETERMINATION
USING LORAN-C TRIPLETS WITH A
BASIC PROGRAM FOR THE
COMMODORE 2001 MICROCOMPUTER

by

R. H. Shudde

March 1980

Approved for public release; distribution unlimited.

Prepared for:

Naval Research
, Virginia 22217

NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA

Rear Admiral J. J. Ekelund
Superintendent

Jack R. Borsting
Provost

The work reported herein was supported by the Office of Naval Research, Fleet Acitivity Support Division, Code 230 and the Commander, Patrol Wings Pacific as part of the Tactical Development and Evaluation Program.

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER NPS55-80-009	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) AN ALGORITHM FOR POSITION DETERMINATION USING LORAN-C TRIPLETS WITH A BASIC PROGRAM FOR THE COMMODORE 2001 MICROMPUTER		5. TYPE OF REPORT & PERIOD COVERED Technical 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) R. H. Shudde		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, Ca. 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 65155N,R0130,NR 128-217 N0001479WR90234
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, CA 93940		12. REPORT DATE March 1980 13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Loran, Loran-C, Navigation, Position determination, Fixing, Hyperbolic Fixing, Radio Positioning, Geodetics, Geodetic Distances

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An algorithm for position determination using Loran-C triplets and an implementation of the algorithm in the BASIC language of the Commodore 2001 microcomputer are presented. Modifications of the geodesic direct solution and reverse solution algorithms of P. D. Thomas are also presented; these modifications eliminate all of the special positioning and quadrant determination requirements of the original algorithms.

AN ALGORITHM FOR POSITION DETERMINATION USING LORAN-C TRIPLETS WITH A BASIC PROGRAM FOR THE COMMODORE 2001 MICROCOMPUTER

by

R. H. Shudde

Naval Postgraduate School
Monterey, CA 93940

March 1980

The program in this report is for use within the Navy and is presented without representation or warranty of any kind.

CONTENTS

ABSTRACT

An algorithm for position determination using Loran-C triplets and an implementation of the algorithm in the BASIC language of the Commodore 2001 microcomputer are presented. Modifications of the geodesic *direct* solution and *reverse* solution algorithms of P. D. Thomas are also presented; these modifications eliminate all of the special positioning and quadrant determination requirements of the original algorithms.

A. Introduction

Loran-C position determination programs for the Hewlett-Packard HP-67 programmable calculator for use aboard U. S. Navy patrol aircraft (P-3) have been prepared and are reported elsewhere [Ref. 1]. During the development and testing of the HP-67 programs the need for a high accuracy program for cross checking purposes arose. The program presented here was developed as a refinement of the HP-67 algorithm.

The basic methodology of this program is contained in the formulas of Paul D. Thomas [Ref. 2] for the *direct* and *reverse* problems of oblate spheroidal geodesy. The *direct* problem is to determine the latitude and longitude of a point P_2 when the latitude and longitude of a point P_1 as well as the azimuth and distance of P_2 from P_1 are known. The *reverse* (or *inverse*) problem is to determine the distance, forward azimuth, and backward azimuth between two points, P_1 and P_2, when the latitude and longitude of both P_1 and P_2 are known. In both problems P_1 and P_2 are on the surface of a spheroid. Unfortunately, Thomas' algorithms contain several restrictions and numerous subcases that are too awkward to be programmed on the HP-67. For this reason portions of these algorithms were rewritten so as to eliminate all of the original restrictions and subcases. These modified algorithms for the *direct* and *reverse* problems are presented here with notations about the modifications made.

B. Loran-C Fixing Algorithms

The principles of Loran lines of position (LOP's) and fixing are adequately covered in Reference 3 and will not be repeated here.

The basic Loran-C equation [Ref. 4] can be written as

$$T = [T_S + p(T_S)] - [T_M + p(T_M)] + [T_B + p(T_B)] + \delta \qquad (1)$$

where

T is the "indicated time difference" in microseconds,

T_M is the distance, in microseconds, from the master to the receiver,

T_S is the distance, in microseconds, from the slave to the receiver,

T_B is the distance, in microseconds, between the master and the slave,

δ is the assigned coding delay, in microseconds,

and $p(T)$ is the secondary phase correction, in microseconds, for a surface water path of length T.

The quantity

$$\Delta t = [T_B + p(T_B)] + \delta$$

is a constant for each master/slave pair. The following World Geodetic System 1972 (WGS 72) values have been adopted for Loran-C navigation [Ref. 4]:

v_0 = 299792458 meters/second is the velocity of light in free space,

η = 1.000338 is the index of refraction of the surface of the earth for standard atmosphere and 100 kHz electromagnetic waves,

a_e = 6378135.000 meters is the equatorial radius of the earth

and f = 1/298.26 is the flattening factor ($1-b/a_e$, where b is the polar radius) of the earth.

With these parameters the secondary phase correction for an all seawater path has been taken to be of the form

$$p(T) = a_0/T + a_1 + a_2T \qquad (2)$$

where T is in microseconds and,

1. For T>537 μsec:

   a_0 = 129.04398,

   a_1 = -0.40758,

   and a_2 = 0.00064576438.

2. For T<537 μsec:

   a_0 = 2.7412979,

   a_1 = -0.011402,

   and a_2 = 0.00032774624.

If one uses a spherical approximation to the earth's surface (f = 0), then a spherical hyperbola can be represented by the equation [Ref. 3, page 175]

$$\tan r = 2\,\frac{\cos 2a - \cos 2c}{\sin 2c \cos \omega + \zeta \sin 2a} \qquad (3)$$

where the origin of the coordinate system is at the prime focus of the spherical hyperbola, 2c is the spherical arc joining the foci, 2a is a constant for any one hyperbola, and r and ω are the spherical coordinates of a point on the hyperbola. If the base line of the coordinate system is the arc joining the foci then ω is the spherical polar angle from the baseline to a point P on the spherical hyperbola and r is spherical polar distance (or arc) from the prime focus to P. Using the Loran system we take $\zeta = +1$ if the prime focus is at a master station and we take $\zeta = -1$ if the prime focus is at a slave station.

If we take $v = v_0/\eta$ to be the velocity of 100kHz electromagnetic radiation at the earth's surface then, for a spherical earth, we can relate the parameters in Equations 1 and 3 as follows:

$$2c = vT_B/a_e,$$

and

$$2a = v(T_S - T_M)/a_e.$$

Using the spherical approximation for now, we see that 2c is known for any Loran pair. The "indicated time delay" T is measured by the receiver at point P, and to determine a hyperbolic line of position we must determine 2a, but $T_S - T_M$ cannot be computed from Equations 1 and 2. If a_0 were zero in Equation 2, then it would be possible to determine $T_S - T_M$ uniquely. As a first approximation we use the following parameters in Equation 2:

$$a_0 = 0,$$

$$a_1 = -0.321,$$

and

$$a_2 = 0.000635.$$

These values have been obtained by setting $a_0 = 0$ and determining

a_1 and a_2 by linear regression of the $T > 537$ values over the interval of $1000 < T < 8000$. This approximation is quite good (within 0.03 μs) for distances up to 10,000 microseconds where small changes in the LOP's can cause large position errors. At short distances the error increases from 0.05 μs at 1000 μs to 0.58 μs at 10 μs; although these errors are large for small distances, the LOP's are not as sensitive to these changes as they would be at large distances. These errors are well within the 4 n.mi (24 μs) accuracy that was requested by COMPATWINGSPAC. When this approximation is substituted into Equation 1, we obtain

$$[T_S + a_1 + a_2 T_S] - [T_M + a_1 + a_2 T_M] = T - \Delta t,$$

or

$$T_S - T_M = (T - \Delta t)/(1 + a_2) \tag{4}$$

and hence $2a = v(T_S - T_M)/a_e$ is determined for use in the spherical approximation.

Consider a Loran-C triplet with the master stations colocated. Let ξ_1 and ξ_2 denote the azimuth angles of slave 1 (S_1) and slave 2 (S_2), respectively, measured from North toward the East from the master stations (M) (see Figure 1). Further, let α and r be the azimuth and spherical polar arc (distance) of the receiver (R) from M. For this geometry, Equation 3 can be written in the form

$$\tan r_i = \frac{B_i}{C_i \cos(\alpha - \xi_i) + A_i}, \tag{5}$$

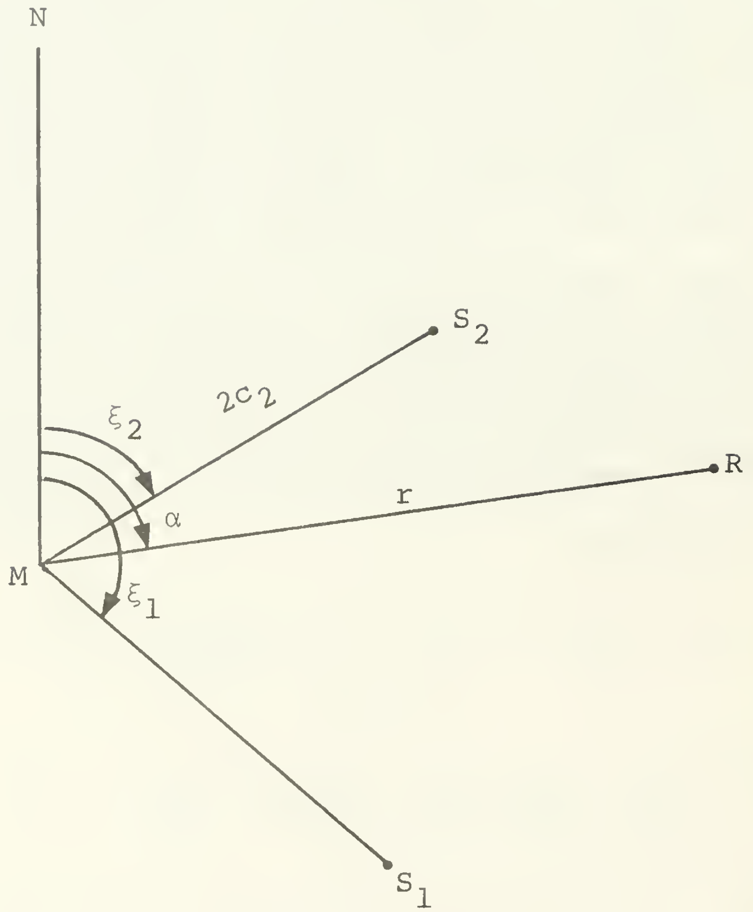


Figure 1. Geometry of a Loran Triplet and a Receiver.

where

$$A_i = \zeta_i \sin 2a_i,$$

$$B_i = \cos 2a_i - \cos 2c_i,$$

and $$C_i = \sin 2c_i$$

for the i^{th} Loran pair, $i = 1,2$. Since $r_1 = r_2 = r$, we can eliminate $\tan r$ between the two equations. The resulting equation can be rewritten as

$$C \cos \alpha + S \sin \alpha = K, \tag{6}$$

where

$$C = B_1C_2 \cos \xi_2 - B_2C_1 \cos \xi_1,$$

$$S = B_1C_2 \sin \xi_2 - B_2C_1 \sin \xi_1,$$

and $$K = B_2A_1 - B_1A_2.$$

If we define $\rho > 0$ and γ by the equations

$$\rho \cos \gamma = C, \tag{7}$$

and $$\rho \sin \gamma = S,$$

then

$$\rho = \sqrt{C^2 + S^2},$$

and $$\gamma = \text{qatn}\ (S,C).$$

Here the function qatn(y,x) is the arctangent of y/x adjusted for the proper quadrant according to the signs of x and y.

A compact form of this function is

$$\text{qatn}(y,x) = \tan^{-1} \frac{y}{x + 10^{-9}\, t(x = 0?)} + \pi t(x < 0?)$$

where $t(z) = 1$ when z is true

and $t(z) = 0$ when z is false.

When convenient we will use the notation qatn(y/x) interchangeably with qatn(y,x). Now we can substitute Eq.(7) into Eq.(6) and solve for

$$\alpha = \gamma \pm \cos^{-1}(K/\rho) \tag{8}$$

to obtain the azimuth angle α of the two points of intersection of the spherical hyperbolic LOP's. Finally we can obtain a value for r by substituting each α into either Eq. (5). We find that

$$r = \text{qatn}\left[\frac{B_i}{C_i \cos(\alpha - \xi_i) + A_i}\right] \quad \text{for } i = 1 \text{ or } 2.$$

To obtain the first solution, r and α are entered into the "direct" solution algorithm; latitude ϕ and longitude λ are the outputs.

The solution is improved using a two-variable Newton-Raphson search for the zeroes of the functions

$$f_i(\phi, \lambda) \equiv f_i = (d_{Si} - d_M)/a_e - 2a_i \quad \text{for } i = 1,2,$$

where d_M, d_{S1}, and d_{S2} are the distances from R to M, S_1, and S_2, respectively, and are computed using the "inverse" solution algorithm. The flow of the improvement algorithm follows:

1. Input the latest approximation to the receiver latitude ϕ and longitude λ.

2. Compute d_M, d_{S1} and d_{S2} using the "inverse" solution algorithm.

3. Compute $T_M = d_M/v$ and $T_{Si} = d_{Si}/v$ for $i = 1,2$.

4. Compute $T_{Si} - T_M = (T-\Delta t)_i - p(T_{Si}) + p(T_M)$ and $2a_i = v(T_{Si}-T_M)/a_e$ for $i = 1,2$.

5. Compute $f_i(\phi,\lambda) = (d_{Si}-d_M)/a_e - 2a_i$ for $i = 1,2$.

6. Compute

$$\frac{\partial f_i}{\partial \phi} = \frac{f_i(\phi + \Delta\phi,\lambda) - f_i(\phi,\lambda)}{\Delta\phi}$$

and

$$\frac{\partial f_i}{\partial \lambda} = \frac{f_i(\phi,\lambda + \Delta\lambda) - f_i(\phi,\lambda)}{\Delta\lambda} \quad \text{for } i = 1,2.$$

($\Delta\lambda = \Delta\phi = 10^{-4}$ radians is used in the BASIC program.)

7. Replace ϕ by

$$\phi - \left[f_1 \frac{\partial f_2}{\partial \lambda} - f_2 \frac{\partial f_1}{\partial \lambda}\right] \bigg/ J$$

and replace λ by

$$\lambda - \left[f_1 \frac{\partial f_2}{\partial \phi} - f_2 \frac{\partial f_1}{\partial \phi}\right] \bigg/ J$$

where

$$J = \frac{\partial f_1}{\partial \phi} \frac{\partial f_2}{\partial \lambda} - \frac{\partial f_1}{\partial \lambda} \frac{\partial f_2}{\partial \phi}$$

8. Repeat from Step 1 until ϕ and λ are stationary.

C. The Direct Solution Algorithm

This *direct* solution algorithm is a modification of the second order in flattening (f) algorithm given by Thomas [Ref. 2, pp. 7-8]. Thomas' notation has been followed as closely as possible for ease of comparison of the algorithms. The qatn function is defined in the previous section. West longitudes and South latitudes are negative. We are given the point $P_1(\phi_1, \lambda_1)$ on the spheroid, where ϕ_1, λ_1 are the geodetic latitude and longitude (geographic coordinates); the forward azimuth α_{12} and distance S to a second point $P_2(\phi_2, \lambda_2)$; and from these we are to find the geographic coordinates ϕ_2, λ_2 and the back azimuth α_{21}. The given quantities are ϕ_1, λ_1, α_{12} and S. No assumptions about the relative location of P_1 and P_2 are required. The modified *direct* solution algorithm is:

$$\theta_1 = \tan^{-1}[(1-f) \tan \phi_1], \quad M = \cos \theta_1 \sin \alpha_{12},$$

$$N = \cos \theta_1 \cos \alpha_{12}, \quad c_1 = fM, \quad c_2 = f(1-M^2)/4,$$

$$D = (1 - c_2)(1 - c_2 - c_1 M), \quad P = c_2[1 + (1/2)c_1 M]/D \ ,$$

$$\sigma_1 = \text{qatn}(N, \sin \theta_1), \quad d = S/(a_e D),$$

$$u = 2(\sigma_1 - d), \quad W = 1-2P \cos u, \quad V = \cos (u+d),$$

$$X = c_2^{\,2} \sin d \cos d \ (2V^2-1), \quad Y = 2PVW \sin d,$$

$$\Delta\sigma = d + X - Y, \ \Sigma\sigma = 2\sigma_1 - \Delta\sigma,$$

$$\alpha_{21} = \text{qatn}[-M, -(N \cos \Delta\sigma - \sin \theta_1 \sin \Delta\sigma)] \ ,$$

$$K = (1-f)[M^2 + (N \cos \Delta\sigma - \sin \theta_1 \sin \Delta\sigma)^2]^{1/2} ,$$

$$\phi_2 = \tan^{-1}[(\sin \theta_1 \cos \Delta\sigma + N \sin \Delta\sigma)/K] ,$$

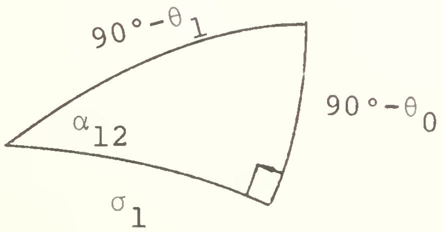
$$\Delta\eta = \mathrm{qatn}(\sin \Delta\sigma \sin \alpha_{12}, \cos \theta_1 \cos \Delta\sigma - \sin \theta_1 \sin \Delta\sigma \cos \alpha_{12}),$$

$$H = c_1(1-c_2)\Delta\sigma - c_1 c_2 \sin \Delta\sigma \cos \Sigma\sigma,$$

$$\Delta\lambda = \Delta\eta - H, \quad \lambda_2 = \lambda_1 + \Delta\lambda$$

In addition to the introduction of the qatn function for proper quadrant determination the following changes have been made to the original algorithm:

1. θ_0 is no longer computed from the equation $M = \cos \theta_0$. Since P_1 is no longer required to be westerly of P_2, α_{12} is no longer required to lie in the interval $[0, 180^\circ]$. Consequently M, which was originally required to be positive, can be negative. With this change θ_0 was no longer properly determined from $M = \cos \theta_0$.
2. With the elimination of θ_0 the determination of σ_1 from the equation $\cos \sigma_1 = \cos \theta_1/\sin \theta_0$ became impossible. The following figure shows the spherical triangle involving σ_1 and θ_0.



Using the "4-parts formula" [Ref. 5, pg. 12] we can determine σ_1 directly from the equation

$$\sigma_1 = \text{qatn}(\cos\theta_1 \cos\alpha_{12}, \sin\theta_1)$$

3. The original equation for ϕ_2,

$$\tan\phi_2 = -(\sin\theta_1 \cos\Delta\sigma + N \sin\Delta\sigma) \sin\alpha_{21}/(1-f)M$$

becomes indeterminate when $\alpha_{12} = 0^\circ$ or 180° since both M and $\sin\alpha_{21}$ become zero simultaneously. From the equation for α_{21} one can determine that

$$\sin\alpha_{21} = -M/[M^2 + (N\cos\Delta\sigma - \sin\theta_1 \sin\Delta\sigma)^2]^{1/2}.$$

Using this equation to eliminate $\sin\alpha_{21}$ in the equation for $\tan\phi_2$ allows the M in the numerator and denominator to cancel thus eliminating the indeterminancy in the equation for ϕ_2.

With these changes the restrictions that P_1 be West of P_2, and that if P_1 and P_2 both have negative latitude the symmetric positive latitude problem be solved, have been eliminated. Also eliminated are rules for the determination of the quadrants of α_{21} and $\Delta\eta$.

D. The Reverse (Inverse) Solution Algorithm

This *reverse* solution algorithm is a modification of the second order in flattening (f) algorithm given by Thomas [Ref. 2, pp. 8-10]. Thomas' notation has been followed as closely as possible for ease of comparison of the algorithms. The qatn function is defined in Section B. West longitudes (λ) and

South latitudes (ϕ) are negative. We are given the points $P_1(\phi_1, \lambda_1)$, $P_2(\phi_2, \lambda_2)$ on the spheroid and are to find the distance S between the points and the forward and back azimuths, α_{12} and α_{21}. Given quantities are ϕ_1, λ_1, ϕ_2 and λ_2. No assumptions about the relative location of P_1 and P_2 are required. The modified *reverse* solution algorithm is:

$$\theta_i = \tan^{-1}[(1-f) \tan \phi_i], \quad i = 1,2,$$

$$\theta_m = (\theta_1+\theta_2)/2, \quad \Delta\theta_m = (\theta_2-\theta_1)/2, \quad \Delta\lambda = \lambda_2 - \lambda_1,$$

$$\Delta\lambda_m = \Delta\lambda/2, \quad H = \cos^2 \Delta\theta_m - \sin^2 \theta_m = \cos^2 \theta_m - \sin^2 \Delta\theta_m = \cos \theta_1 \cos \theta_2$$

$$L = \sin^2 \Delta\theta_m + H \sin^2 \Delta\lambda_m = \sin^2(d/2),$$

$$1-L = \cos^2(d/2), \quad d = \cos^{-1}(1-2L),$$

$$U = 2 \sin^2 \theta_m \cos^2 \Delta\theta_m/(1-L), \quad V = 2 \sin^2 \Delta\theta_m \cos^2 \theta_m/L,$$

$$X = U + V, \quad Y = U - V, \quad T = d/\sin d, \quad D = 4T^2,$$

$$E = 2 \cos d, \quad A = DE, \quad B = 2D, \quad C = T - (A-E)/2$$

$$n_1 = X(A+CX), \quad n_2 = Y(B+EY), \quad n_3 = DXY,$$

$$\delta_1 d = f(TX-Y)/4, \quad \delta_2 d = f^2(n_1-n_2+n_3)/64,$$

$$S = a_e(T-\delta_1 d+\delta_2 d) \sin d, \quad F = 2Y - E(4-x)$$

$$M = 32T - (20T-A)X - (B+4)Y,$$

$$G = fT/2 + f^2M/64, \quad Q = -(FG \tan \Delta\lambda)/4,$$

$$\Delta\lambda_m' = (\Delta\lambda + Q)/2,$$

$$t_1 = \text{qatn}(-\sin \Delta\theta_m \cos \Delta\lambda_m', \cos \theta_m \sin \Delta\lambda_m'),$$

$$t_2 = \text{qatn}(\cos \Delta\theta_m \cos \Delta\lambda_m', \sin \theta_m \sin \Delta\lambda_m'),$$

$$\alpha_{12} = t_1 + t_2, \quad \alpha_{21} = t_1 - t_2$$

The only changes made to the original algorithm are the computation of t_1 and t_2 and the determination of α_{12} and α_{21} as the sum and difference of t_1 and t_2. Minor though these changes may seem, they have eliminated the requirement that P_1 is West of P_2 and they have eliminated four cases for the quadrant determination of α_{12} and α_{21}. Quadrant determination is still required, but it is implemented with the qatn function; the qatn function is available on the better handheld calculators in the form of the rectangular-to-polar function.

E. Program Accuracy

Several programs were written for the Commodore 2001 computer. One program implemented only the *direct* and *reverse* solution algorithms presented in the previous two sections. Initially these algorithms were validated against the long line computations with the Clarke 1866 spheroid model presented in Reference 2. Later the *reverse* solution algorithm was compared with the WGS 72 data for 40 Loran-C pairs contained in Reference 4 (data for the 9930 stations were not included). In these comparisons the algorithm error for the baseline distances was 0.16 meters high for the 7980W pair and 0.15 meters low for the 7980Y pair. For the remaining stations all of the baseline errors were high, but the largest error was only 0.08 meters. It should be mentioned that the Microsoft BASIC for the Commodore 2001 carries 10 digits of floating point internally, but will display only a maximum of nine digits; the baselines reported in Reference 4 are printed to the nearest 0.0001 meters. The computed one way baseline time plus secondary phase correction was also computed and compared to the 40 Loran-C pairs data. In three cases the algorithm was high by 0.01 μs, in three cases the algorithm was low by 0.01 μs, and there was no error in the remaining cases.

Another program was used to generate the indicated time delay between Loran-C pairs and test positions for a receiver. Combining the time delay for Loran-C pairs into allowable triplets enabled the position fixing program in the Appendix to be evaluated. Typical results are presented in Table I. In all cases the Commodore 2001, running at BASIC interpreter speed required 8 seconds from entry of the time delay input to the display of the first pair of solutions. The improvement algorithm will improve only one user selected solution. Each iteration requires 14.4 seconds, and each improvement is displayed so that the user can monitor the improvement process. Usually the solution has stabilized after two iterations, but occasionally a third iteration is generated. In Table I the worst fix took six iterations for the triplet comprised of pairs 9930W and 9930X where the radial position error is 0.91 n.mi. In fairness to the algorithm it should be noted that the three stations are 776 n.mi, 2130 n.mi, and 2514 n.mi from the receiver and are all within 6° of azimuth as viewed from the receiver.

Table I

Receiver Location: 52°N, 35°W

Station Pair	Computed Delay	Station Pair	Computed Delay
7970W	32845.12	7930W	16673.77
7970X	18889.03	7930X	30899.81
9930W	16067.09	7930Z	49369.30
9930X	28012.61		

Triad	First Solution	Improved Solution	No. Iter.
7970W/7970X	52°00'14"N, 34°59'34"W	52°00'00".14N, 34°59'59".66W	2
9930W/9930X	51°56'13"N, 35°21'23"W	51°59'45".25N, 35°01'25".37W	6
7930W/7930X	52°00'01"N, 35°00'01"W	51°59'59".69N, 35°00'00".02W	2
7930W/7930Z	52°00'01"N, 35°00'01"W	52°00'00".03N, 35°00'00".07W	2
7930X/7930Z	52°00'01"N, 35°00'01"W	52°00'00".00N, 34°59'59".96W	2
7930X/7970W	52°00'04"N, 34°59'57"W	52°00'00".01N, 34°59'59".96W	2
7930Z/9930X	51°59'52"N, 34°59'26"W	51°59'59".60N 34°59'58".27W	2

F. References

1. R. H. Shudde, "Position Determination with LORAN-C Triplets and the Hewlett-Packard HP-67/97 Programmable Calculators", Technical Report NPS-55-80-010, March 1980, Naval Postgraduate School, Monterey, CA 93940.

2. Paul D. Thomas, "Spheroidal Geodesics, Reference Systems, and Local Geometry", SP-138, U.S. Naval Oceanographic Office,Washington, D.C., January 1970.

3. J. A. Pierce, A. A. McKenzie, and R. H. Woodward, editors, *LORAN*, M.I.T. Radiation Laboratory Series, McGraw-Hill Book Company, Inc., 1948.

4. *LORAN HYPERBOLIC LOP FORMULAS* and *GENERAL SPECIFICATIONS FOR THE LORAN-C* (20 June 1977) were obtained from G. R. Deyoung, Acting Chief, Navigation Department, Defense Mapping Agency, Hydrographic/Topographic Center, Washington, D. C. by private communication, 5 March 1980.

5. W. M. Smart, *Spherical Astronomy*, Fifth Edition, Cambridge University Press, 1965.

APPENDIX. BASIC Program Listing

This appendix contains the listing of the BASIC position fixing program for the Commodore 2001. A number of the cursor control and formatting symbols on the listing require explanation. These symbols are given below by line number at first occurrence.

130 Reverse field 'heart' means 'clear the screen'

130 Reverse field 'Q' means 'move cursor down'

250 Reverse field 'R' means 'turn on field reverse'

250 Reverse field '_' means 'turn off field reverse'

250 Use of the field reverse symbols highlights the 'Y' in 'YES' and the 'N' in 'NO' to prompt the user to type a 'Y' or 'N' on the keyboard. Similar highlighting is used on lines 390, 790, 800 and 810

740 CHR$(34) generates the double quote symbol to designate 'seconds of arc'

740 The symbol between the double quotes which are between N$(1) and N$(2) is used to designate '^{o}', the 'degrees of arc' symbol

910 The first symbol following the double quote means 'move cursor up', and the next symbols each mean 'move cursor right'

The DATA statements on lines 50001 through 50044 contain the pertinent parameters for each Loran-C pair. The fields contain:

1. The Loran-C station pair designator.

2. Δt, the sum of the coding delay plus one way baseline time, including the secondary phase correction for an all seawater path, in microseconds.

3. The master station latitude.

4. The master station longitude.

5. The slave station latitude.

6. The slave station longitude.

Negative longitudes are West longitudes. The latitudes and longitudes appear to be in decimal form, but the actual format is DDD.MMSSFF where

DDD designates degrees,

MM designates minutes,

SS designates seconds,

and FF designates hundredths of seconds.

```
50001 DATA 4990X,15972.23,16.444395,-169.303120,20.144916,-155.530970
50002 DATA 4990Y,34253.18,16.444395,-169.303120,28.234177,-178.173020
50003 DATA 5930X,13131.88,46.482720,-067.553771,41.151193,-069.583909
50004 DATA 5930Y,28755.02,46.482720,-067.553771,46.463218,-053.102816
50005 DATA 5990X,13343.60,51.575878,-122.220224,55.262085,-131.151965
50006 DATA 5990Y,28927.36,51.575878,-122.220224,47.034799,-119.443953
50007 DATA 5990Z,42266.63,51.575878,-122.220224,50.362972,-127.212935
50008 DATA 7930W,15068.02,59.591727,-045.102747,64.542658,-023.552175
50009 DATA 7930X,27803.77,59.591727,-045.102747,62.175968,-007.042671
50010 DATA 7930Z,48212.20,59.591727,-045.102747,46.463218,-053.102816
50011 DATA 7960X,13804.45,63.194281,-142.483190,57.262021,-152.221122
50012 DATA 7960Y,29651.14,63.194281,-142.483190,55.262085,-131.151965
50013 DATA 7970W,30065.64,62.175968,-007.042671,54.482980,+008.173633
50014 DATA 7970X,15048.10,62.175968,-007.042671,68.380615,+014.274700
50015 DATA 7970Y,48944.53,62.175968,-007.042671,64.542658,-023.552175
50016 DATA 7970Z,63216.30,62.175968,-007.042671,70.545261,-008.435869
50017 DATA 7980W,12809.54,30.593874,-085.100930,30.433302,-090.494360
50018 DATA 7980X,27443.38,30.593874,-085.100930,26.315501,-097.500009
50019 DATA 7980Y,45201.88,30.593874,-085.100930,27.015849,-080.065352
50020 DATA 7980Z,61542.72,30.593874,-085.100930,34.034604,-077.544676
50021 DATA 7990X,12755.97,38.522061, 016.430596,35.312088, 012.312996
50022 DATA 7990Y,32273.30,38.522061, 016.430596,40.582095, 027.520152
50023 DATA 7990Z,50999.69,38.522061, 016.430596,42.033649, 003.121590
50024 DATA 8970W,14355.11,39.510754,-087.291214,30.593874,-085.100930
50025 DATA 8970X,31162.06,39.510754,-087.291214,42.425060,-076.493386
50026 DATA 8970Y,47753.74,39.510754,-087.291214,48.364984,-094.331847
50027 DATA 9930W,13695.51,34.034604,-077.544676,27.015849,-080.065352
50028 DATA 9930X,36389.66,34.034604,-077.544676,46.463218,-053.102816
50029 DATA 9930Y,52541.31,34.034604,-077.544676,41.151193,-069.583909
50030 DATA 9930Z,68560.72,34.034604,-077.544676,39.510754,-087.291214
50031 DATA 9940W,13796.90,39.330662,-118.495637,47.034799,-119.443953
50032 DATA 9940X,28094.50,39.330662,-118.495637,38.465699,-122.294453
50033 DATA 9940Y,41967.30,39.330662,-118.495637,35.191818,-114.481743
50034 DATA 9960W,13797.20,42.425060,-076.493386,46.482720,-067.553771
50035 DATA 9960X,26969.93,42.425060,-076.493386,41.151193,-069.583909
50036 DATA 9960Y,42221.65,42.425060,-076.493386,34.034604,-077.544676
50037 DATA 9960Z,57162.06,42.425060,-076.493386,39.510754,-087.291214
50038 DATA 9970W,15283.94,24.48041 , 141.19290 ,24.17077 , 153.58515
50039 DATA 9970X,36685.12,24.48041 , 141.19290 ,42.443700, 143.430906
50040 DATA 9970Y,59463.18,24.48041 , 141.19290 ,26.362499, 128.085621
50041 DATA 9970Z,80746.79,24.48041 , 141.19290 ,09.324566, 138.095523
50042 DATA 9990X,14875.32,57.090988,-170.145981,52.494505,+173.105231
50043 DATA 9990Y,32069.09,57.090988,-170.145981,65.144012,-166.531447
50044 DATA 9990Z,46590.10,57.090988,-170.145981,57.262021,-152.221122
```

```
10 REM LORAN NAVIGATION: 01-13-80. REV 03-18-80. R. SHUDDE
20 NP=44:REM NUMBER OF LORAN PAIRS ABOARD.
30 DIM ID$(NP),DT(NP),PS(2,2,NP):REM 1ST ARG=LAT,LONG. 2ND ARG=(M),(S). 3RD=ID
40 TP=π+π:RD=π/180:DEFFNS(X)=SIN(X*RD):DEFFNC(X)=COS(X*RD):DEFFNT(X)=TAN(X*RD)
50 DEFFNM(X)=X-360*INT(X/360):DEFFNR(X)=INT(100*X+.5)/100
60 FL=1/298.26:AE=6378135:CC=299792.458E3:REM AE IN METERS, CC IN M/SEC
70 AE=AE/CC*1E6:REM AE IS IN MICROSECONDS
80 IR=1.000338:REM INDEX OF REFRACTION OF AIR
90 GM=.000634:REM SECONDARY PHASE APPROXIMATION
92 DEFFNP(X)=129.04398/X-.40758+6.4576438E-4*X
94 DEFFNQ(X)=2.7412979/X-.011402+3.2774624E-4*X
100 AX=1+GM:AY=AE*IR
110 PRINT"                 LOADING.
120 FORI=1TONP:READID$(I),DT(I):FORK=1TO2:FORJ=1TO2:READPS(J,K,I):NEXTJ,K,I
130 PRINT"
140 PRINT"INPUT THE ID'S OF THE LORAN PAIRS
150 PRINT"IN THE TRIPLET.
160 INPUT"  1ST ID";M$(1):FORI1=1TONP:IFID$(I1)=M$(1)GOTO180
170 NEXTI1:PRINT"  THAT ID IS NOT IN THE CATALOG. PLEASE REENTER.":GOTO160
180 INPUT"  2ND ID";M$(2):FORI2=1TONP:IFID$(I2)=M$(2)GOTO200
190 NEXTI2:PRINT"  THAT ID IS NOT IN THE CATALOG. PLEASE REENTER.":GOTO180
200 PRINT"";TAB(6);"YOUR STATION ID'S ARE
210 FORI=1TO2:PRINTTAB(13);M$(I):NEXTI
220 PRINTTAB(8);"ANY CORRECTIONS?"
230 PRINTTAB(11);"YES OR NO.
240 ID%(1)=I1:ID%(2)=I2
250 GETG$:IFG$=""GOTO250
260 IFG$="N"THENPRINT"                OK":GOTO300
270 IFG$<>"Y"GOTO250
280 GOTO130
290 REM DETERMINE CO-LOCATED STATIONS
300 IFPS(1,1,I1)=PS(1,1,I2)ANDPS(2,1,I1)=PS(2,1,I2)THENL1=1:L2=1:GOTO430
```

```
310 IFPS(1,2,I1)=PS(1,2,I2)ANDPS(2,2,I1)=PS(2,2,I2)THENL1=-1:L2=-1:GOTO430
320 IFPS(1,1,I1)=PS(1,2,I2)ANDPS(2,1,I1)=PS(2,2,I2)THENL1=1:L2=-1:GOTO430
330 IFPS(1,2,I1)=PS(1,1,I2)ANDPS(2,2,I1)=PS(2,1,I2)THENL1=-1:L2=1:GOTO430
340 PRINT"YOUR LORAN STATIONS"
350 FORI=1TO2:PRINTTAB(13);M$(I):NEXTI:PRINT"DO NOT FORM A LORAN TRIPLET.
360 PRINT"WE CANNOT CONTINUE.
370 PRINT"PRESS C TO CONTINUE OR E TO END.
380 GETG$:IFG$=""GOTO380
390 IFG$="C"GOTO130
400 IFG$<>"E"GOTO380
410 END
420 REM SET UP TRIPLET AND COMPUTE BASELINES
430 K1=1:K2=2:IFL1<0THENK1=2:K2=1
440 X=0:FORI=K1TOK2STEPK2-K1
450 L=PS(1,I,I1):GOSUB1290:PH(X)=L:L=PS(2,I,I1):GOSUB1290:LM(X)=L:X=X+1:NEXTI
460 K1=2:IFL2<0THENK1=1
470 L=PS(1,K1,I2):GOSUB1290:PH(2)=L
480 L=PS(2,K1,I2):GOSUB1290:LM(2)=L
490 H%=0:K1=0:FORK2=1TO2:GOSUB1150:C2(K2)=S2/AE:AZ(K2)=A(1):I%=ID%(K2)
500 LB(K2)=100*INT((DT(I%)-S2)/100+.5):UB(K2)=LB(K2)+2*(DT(I%)-LB(K2)):NEXTK2
510 REM COMPUTE TWO SOLUTIONS
520 PRINT"
530 PRINT"INPUT TIME FOR ";ID$(I1);:INPUTIT(1)
540 IFLB(1)<=IT(1)ANDIT(1)<=UB(1)GOTO560
550 PRINTIT(1);"IS NOT VALID. PLEASE RE-ENTER.":GOTO530
560 PRINT"INPUT TIME FOR ";ID$(I2);:INPUTIT(2)
570 IFLB(2)<=IT(2)ANDIT(2)<=UB(2)GOTO590
580 PRINTIT(2);"IS NOT VALID. PLEASE RE-ENTER.":GOTO560
590 Q2(1)=L1*(IT(1)-DT(I1))/AY:Q2(2)=L2*(IT(2)-DT(I2))/AY
600 A2(1)=Q2(1)/AX:A2(2)=Q2(2)/AX
```

```
610 FORI=1TO2:B(I)=COS(A2(I))-COS(C2(I)):C(I)=SIN(C2(I)):A(I)=SIN(A2(I)):NEXTI
620 BC=B(1)*C(2)*COS(AZ(2))-B(2)*C(1)*COS(AZ(1))
630 BS=B(1)*C(2)*SIN(AZ(2))-B(2)*C(1)*SIN(AZ(1))
640 BK=B(2)*A(1)-B(1)*A(2)
650 LA=SQR(BC*BC+BS*BS):Y=BS:X=BC:GOSUB1460:AL=AT
660 Y=SQR(LA*LA-BK*BK):X=BK:GOSUB1460:KL=AT
670 SN=-1:FORI=1TO2:SN=-SN:NU=AL+SN*KL
680 Y=B(1):X=C(1)*COS(NU-AZ(1))+A(1):GOSUB1460:R=AT:R(I)=R
690 TH=TH(0):LM=LM(0):AZ=NU/RD:S=R*AE:GOSUB1330
700 REM SP=SIN(TH(0))*COS(R)+COS(TH(0))*SIN(R)*COS(NU)
710 REM TN=SP/SQR(1-SP*SP):TL(I)=ATN(TN):LT=ATN(TN/(1-FL))/RD
720 REM Y=SIN(R)*SIN(NU):X=COS(TH(0))*COS(R)-SIN(TH(0))*COS(NU)*SIN(R)
730 REM GOSUB10400:LN=AT/RD+LM(0)
740 PRINT"■SOLUTION";I
750 SL(1,I)=P2:A=P2:GOSUB1480:NQ$=" N":IFNS$="-"THENNQ$=" S"
760 PRINT"    LATITUDE  = ";N$(1);"°";N$(2);"'";N$(3);CHR$(34);NQ$
770 SL(2,I)=Z2:A=Z2:GOSUB1480:NQ$=" W":IFNS$=" "THENNQ$=" E"
780 PRINT"    LONGITUDE = ";N$(1);"°";N$(2);"'";N$(3);CHR$(34);NQ$
790 NEXTI
800 REM DISPLAY OPTIONS
810 PRINT"■■I■MPROVE SOLUTION,
820 PRINT"■N■EW STATIONS OR
830 PRINT"■S■AME STATIONS?
840 GETC$:IFC$=""GOTO840
850 IFC$="S"GOTO520
860 IFC$="N"GOTO130
870 IFC$<>"I"GOTO840
880 REM COMPUTE IMPROVED SOLUTION BY ITERATION
890 PRINT"■IMPROVE SOLUTION ■1■ OR ■2■?
900 GETC$:IFC$=""GOTO900
```

```
910 IFC$="1"GOTO930
920 IFC$<>"2"GOTO900
930 C%=VAL(C$):H%=1:PRINT"]██████████████████████████DK■":R=R(C%):TH=TH(0)
940 LM=LM(0):PH(3)=SL(1,C%):LM(3)=SL(2,C%):DR=1E-4
950 K1=0:K2=3:GOSUB1150:R=S2/AE:PQ=PZ
960 FORK1=1TO2:GOSUB1150:A2(K1)=Q2(K1)-(PZ-PQ)/AY:F(K1)=S2/AE-R-A2(K1)
965 NEXTK1
970 PH(3)=PH(3)+DR
980 K1=0:GOSUB1150:P(1,1)=-S2/AE:P(2,1)=-S2/AE
990 FORK1=1TO2:GOSUB1150:P(K1,1)=(P(K1,1)+S2/AE-A2(K1)-F(K1))/DR:NEXTK1
1000 PH(3)=PH(3)-DR:LM(3)=LM(3)+DR
1010 K1=0:GOSUB1150:P(1,2)=-S2/AE:P(2,2)=-S2/AE
1020 FORK1=1TO2:GOSUB1150:P(K1,2)=(P(K1,2)+S2/AE-A2(K1)-F(K1))/DR:NEXTK1
1030 LM(3)=LM(3)-DR
1040 JK=P(1,1)*P(2,2)-P(1,2)*P(2,1)
1050 IFJK=0THENPRINT"■JACOBIAN = 0. CANNOT IMPROVE":GOTO810
1060 DP=(F(1)*P(2,2)-F(2)*P(1,2))/JK:DL=(F(1)*P(2,1)-F(2)*P(1,1))/JK
1070 PH(3)=PH(3)-DP:LM(3)=LM(3)+DL
1080 A=PH(3):GOSUB1480:NQ$=" N":IFNS$="-"THENNQ$=" S"
1090 PRINT"   LATITUDE  = ";N$(1);"■";N$(2);"'";N$(3);CHR$(34);NQ$
1100 A=LM(3):GOSUB1480:NQ$=" W":IFNS$=" "THENNQ$=" E"
1110 PRINT"   LONGITUDE = ";N$(1);"■";N$(2);"'";N$(3);CHR$(34);NQ$
1120 IFABS(DP)>DRORABS(LD)>DRTHENPRINT:GOTO950
1130 GOTO810
1140 REM REVERSE SOLUTION
1150 FORI=K1TOK2STEPK2-K1:TH(I)=ATN((1-FL)*FNT(PH(I))):NEXTI
1160 TM=(TH(K1)+TH(K2))/2:DT=(TH(K2)-TH(K1))/2:DL=(LM(K2)-LM(K1))*RD:DM=DL/2
1170 H=COS(DT)↑2-SIN(TM)↑2:L=SIN(DT)↑2+H*SIN(DM)↑2:SD=2*ATN(SQR(L/(1-L)))
1180 U=2*((SIN(TM)*COS(DT))↑2)/(1-L):V=2*((SIN(DT)*COS(TM))↑2)/L
1190 X=U+V:Y=U-V:T=SD/SIN(SD):D=4*T*T:E=2*COS(SD):A=D*E:B=D+D
1200 C=T-(A-E)/2:N1=X*(A+C*X):N2=Y*(B+E*Y):N3=D*X*Y
```

```
1210 D1=FL*(T*X-Y)/4:D2=FL*FL*(N1-N2+N3)/64
1220 SN=AE*SIN(SD):S2=SN*(T-D1+D2):IFH%=0GOTO1230
1225 PZ=FNP(S2):IFS2<537THENPZ=FNQ(S2)
1226 RETURN
1230 F=Y+Y-E*(4-X):M=32*T-(20*T-A)*X-(B+4)*Y
1240 G=FL*T/2+FL*FL*M/64:Q=-(F*G*TAN(DL))/4:DP=(DL+Q)/2
1250 Y=-SIN(DT)*COS(DP):X=COS(TM)*SIN(DP):GOSUB1460:T1=AT
1260 Y=COS(DT)*COS(DP):X=SIN(TM)*SIN(DP):GOSUB1460:T2=AT
1270 A(1)=(T1+T2):A(2)=(T1-T2):RETURN
1280 REM DMS TO DEG
1290 S=SGN(L):L=ABS(L)+1/36E6:M1=INT(L):M2=100*(L-M1)
1300 M3=INT(M2):M4=100*(M2-M3)
1310 L=S*((M4/60+M3)/60+M1):RETURN
1320 REM DIRECT SOLUTION
1330 M=COS(TH)*FNS(AZ)
1340 N=COS(TH)*FNC(AZ):C1=FL*M:C2=FL*(1-M*M)/4:D=(1-C2)*(1-C2-C1*M)
1350 P=C2*(1+C1*M/2)/D:Y=N:X=SIN(TH):GOSUB1460:SG=AT
1360 SD=S/(AE*D):SU=2*(SG-SD):W=1-2*P*COS(SU):V=COS(SU+SD)
1370 X=C2*C2*SIN(SD)*COS(SD)*(2*V*V-1)
1380 Y=2*P*V*W*SIN(SD):DS=SD+X-Y:SS=SG+SG-DS
1390 Y=-M:X=-(N*COS(DS)-SIN(TH)*SIN(DS)):GOSUB1460:A2=AT
1400 P2=ATN((SIN(TH)*COS(DS)+N*SIN(DS))/SQR(X*X+Y*Y)/(1-FL))
1410 Y=SIN(DS)*FNS(AZ):X=COS(TH)*COS(DS)-SIN(TH)*SIN(DS)*FNC(AZ)
1420 GOSUB1460:DN=AT
1430 H=C1*(1-C2)*DS-C1*C2*SIN(DS)*COS(SS)
1440 DL=DN-H:Z2=LM+DL/RD:P2=P2/RD:IFZ2>180THENZ2=Z2-360
1450 RETURN
1460 AT=ATN(Y/(X-1E-9*(X=0)))-π*(X<0):RETURN:REM QTAN(Y,X) FUNCTION
1470 REM DEG TO DMS
1480 IFA<-180THENA=A+360
1485 NS$=" ":IFA<0THENNS$="-":A=-A
1490 N(1)=INT(A):A=60*(A-N(1))
1500 N(2)=INT(A):N(3)=INT(60000*(A-N(2)))/1E3
1510 N$(1)=RIGHT$(STR$(1000+N(1)),3)
1520 N$(2)=RIGHT$(STR$(1000+N(2)),2)
1530 N$(3)=MID$(STR$(1000+N(3)),4,6)
1540 RETURN
```

Coverage of Loran-C Systems

Station	Location
4990	Central Pacific
5930	East Coast, Canada
5990	West Coast, Canada
7930	North Atlantic
7960	Gulf of Alaska
7970	Norwegian Sea
7980	Southeast U.S.A.
7990	Mediterranean Sea
8970	Great Lakes
9930	East Coast, U.S.A.
9940	West Coast, U.S.A.
9960	Northeast U.S.A.
9970	Northwest Pacific
9990	North Pacific

INITIAL DISTRIBUTION LIST

	NO. OF COPIES
Defense Technical Information Center Cameron Station Alexandria, VA 22314	2
Library, Code 0212 Naval Postgraduate School Monterey, CA 93940	2
Library, Code 55 Department of Operations Research Naval Postgraduate School Monterey, CA 93940	2
Dean of Research, Code 012 Naval Postgraduate School Monterey, CA 93940	1
Office of Naval Research Fleet Activity Support Division Code ONR-230 800 North Quincy Street Arlington, VA 22217 Attn: Mr. Robert Miller	2
Office of Naval Research Code ONR-434 800 North Quincy Street Arlington, VA 22217	1
Navy Tactical Support Activity P.O. Box 1042 Silver Springs, MD 20910	2
COMPATWINGSPAC Naval Air Station Moffett Field, CA 94035 Attn: Code 51 and Code 532	4
COMPATWING ELEVEN TSC NAS Jacksonville, FL 32212 Attn: LT Jan Smith	1
COMPATWINGSLANT Naval Air Station Brunswick, ME 04011 Attn: Code N7	2
COMSEABASEDASWWINGSLANT Naval Air Station Jacksonville, FL 32228 Attn: TD&E Officer	2

	NO. OF COPIES
Commanding Officer Air Test and Evaluation Squadron 1 (VX-1) Patuxent River, MD 20670 Attn: Code 713	1
Commanding Officer Submarine Development Group Two Groton, CT 06340	1
Director Strategic Systems Project Office 1931 Jefferson Davis Highway Arlington, VA 20376 Attn: Code SP2021	1
Naval Air Development Center Johnsville, PA 18974 Attn: Code 2022	1
Center for Naval Analysis 1401 Wilson Boulevard Arlington, VA 22209 Attn: Greg Watson	1
Naval Weapons Laboratory Dahlgren, VA 22448	1
Naval Weapons Center China Lake, CA 93555	1
Naval Surface Weapons Center White Oak Silver, Spring, MD 20910	1
Naval Research Laboratory Washington, D.C. 20390	1
David Taylor Naval Ship Research and Development Center Bethesda, MD 20034	1
Naval Ocean Systems Center San Diego, CA 92132	1
Naval Intelligence Support Center 4301 Suitland Road Washington, D.C. 20390	1
Naval Electronics Systems Command 2511 Jefferson Davis Highway Arlington, VA 20360	1

	NO. OF COPIES
Naval Underwater Systems Center Code SA33 New London, CT 06320	1
Naval Ship Engineering Center Hyattsville, MD 20782	1
Naval Coastal Systems Laboratory Panama City, FL 32401	1
Naval Air Systems Command Code 370 Washington, D.C. 20361	1
Naval Sea Systems Command Code 03424 Washington, D.C. 20362	1
Naval Underwater Systems Center Newport, Rhode Island 02840	1
Naval Ordnance Station Indian Head, MD 20640	1
Naval Surface Weapons Center Dahlgren, VA 22448	1
Anti-Submarine Warfare Systems Project Office Code ASW-137 Department of the Navy Washington, D.C. 20360	1
Surface Warfare Development Group Naval Amphibious Base Little Creek, VA 23511 Attn: Code N32 and C. Cartledge	2
COMNAVSURFLANT Norfolk, FA 23511 Attn: Code N612	1
Deputy Commander Operational Test and Evaluation Force Pacific NAS North Island San Diego, CA 92135 Attn: Code 202	1
VP-24 NAS Jacksonville, FL 32212 Attn: LTJG Kenneth D. Walker	1

	NO. OF COPIES
Assistent Wing TAC D&E Officer ASW Operations Department NAS Cecil Field, FL 32215 Attn: Code VS-24	1
Naval Electromagnetic Spectrum Center Naval Communications Unit Washington, D.C. 20390 Attn: CDR Claude LaVarre	1
VS-Support Unit NAS Cecil Field, FL 32215 Attn: CWO Wentworth	1
PROCAL-Code 18 Fleet Readiness Office NOSC San Diego, CA 92152 Attn: Jim Grant	1
Chief of Naval Materiel MAT 08D1 Department of the Navy Washington, D.C. 20360 Attn: CDR Philip Harvey	1
LT Jan Smith COMCRUDESGRU TWO FPO New York, NY 09501	1
Dr. Thomas Burnett Dept. of Management Science OR Study Group U.S. Naval Academy Annapolis, MD 21401	1
U. S. Naval Oceanographic Office Washington, D.C. 20309 Attn: Paul D. Thomas	1
Navigation Department Defense Mapping Agency Hydrographic/Topographic Center Washington, D.C. 20315 Attn: G. R. Deyoung	1

	NO. OF COPIES
LT Michael D. Redshaw Helicopter Antisubmarine Squadron 7 FPO New York 09501	1
Mr. Raymond F. Fish Naval Underwater Systems Center Newport, RI 02840	1
LCDR R. R. Hillyer Code N311 Commander, Carrier Group Four FPO New York 09501	1
LT L. R. Erazo ASWOC SIGNOELLA FPO New York 09523	1
LT Richard O. White, J. USS Dwight D. Eisenhower (CVN-69) FPO New York 09501	1
LT David E. Hebdon USS John F. Kennedy (CU-67) FPO New York 09501	1
LT M. D. Clary USS PAIUTE (ATF-159) FPO New York 09501	1
LCDR Robert M. Hanson Helasron Four NAS North Island San Diego, CA 92135	1
LT Michael D. Thomas 2476 Ridgecrest Ave. Orange Park, FL 32073	1
LT Carl E. Garrett, Jr. Class 65, Dept. Head Course Surface Warfare School, Naval Base Newport, RI 02840	1
Naval Postgraduate School Monterey, CA 93940	
Attn: Prof. R. N. Forrest, Code 55Fo	1
Prof. R. H. Shudde, Code 55Su	200
R. J. Stampfel, Code 55	